Pulsed Fission-Fusion Propulsion System (PuFF)

Completed Technology Project (2013 - 2014)

Project Introduction

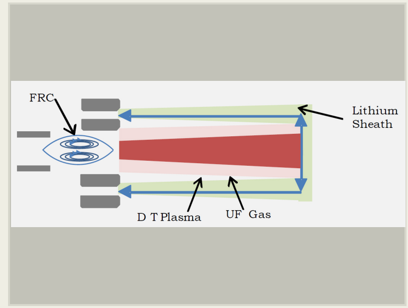
Leveraging insights gained from the weapons physics program, a Z-Pinch device could be used to ignite a thermonuclear deuterium trigger, which could provide a radical improvement in our ability to explore destinations across the solar system and beyond.

Fission-ignited fusion systems have been operational – in weapon form – since the 1950's. Leveraging insights gained from the weapons physics program, a Z-Pinch device could be used to ignite a thermonuclear deuterium trigger. The fusion neutrons will induce fission reaction in a surrounding uranium or thorium liner, releasing sufficient energy to further confine and heat the fusion plasma. The combined energy release from fission and fusion would then be directed using a magnetic nozzle to produce useful thrust. This type of concept could provide the efficiency of open cycle fusion propulsion devices with the relative small size and simplicity of fission systems; and would provide a radical improvement in our ability to explore destinations across the solar system and beyond.

Pulsed Fission-Fusion (PuFF) is a two-stage compression system consisting of a z-pinch and field-reversed configuration.

Anticipated Benefits

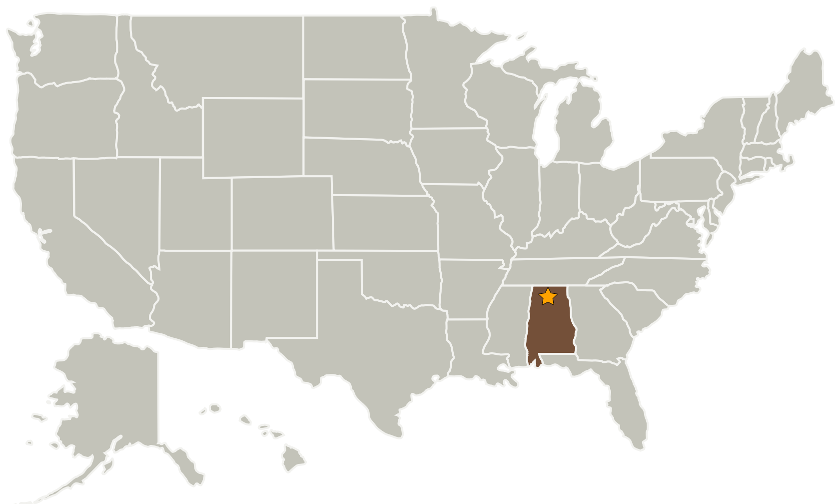
We envision PuFF being used to carry high speed payloads to an existing Martian base. We also considered a robotic probe to the outer solar system and interstellar space. This probe, using the same point design for the engine, carries 10 mT to 1000 AU in 36 years, enabling exploration of the local space around our solar system.



Pulsed Fission-Fusion (PuFF) Propulsion System Project

Table of Contents

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
★Marshall Space Flight Center(MSFC)	Lead Organization	NASA Center	Huntsville, Alabama
ERC Inc.	Supporting Organization	Industry	
International Space Systems, Inc.	Supporting Organization	Industry	
University of Alabama in Huntsville(UAH)	Supporting Organization	Academia	Huntsville, Alabama
Yetispace, Inc.	Supporting Organization	Industry	

Primary U.S. Work Locations
Alabama

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Center / Facility:

Marshall Space Flight Center (MSFC)

Responsible Program:

NASA Innovative Advanced Concepts

Project Management

Program Director:

Jason E Derleth

Program Manager:

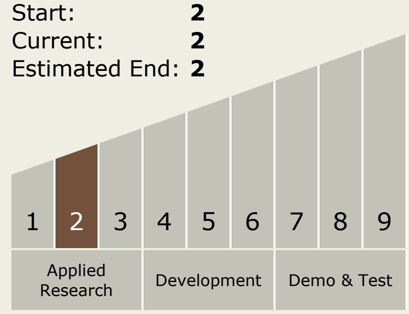
Eric A Eberly

Principal Investigator:

Robert B Adams

Technology Maturity (TRL)

Start: **2**
Current: **2**
Estimated End: **2**



Project Transitions

August 2013: Project Start

Technology Areas

Primary:

- TX01 Propulsion Systems
  └ TX01.4 Advanced Propulsion
    └ TX01.4.4 Other Advanced Propulsion Approaches

Target Destinations

Others Inside the Solar System, Outside the Solar System

April 2014: Closed out

Closeout Summary: In September 2013 the NASA Innovative Advanced Concept (NIAC) organization awarded a phase I contract to the PuFF team. Our phase 1 proposal discussed a pulsed fission-fusion propulsion system that injected gaseous deuterium (D) and tritium (T) as a mixture in a column, surrounded concentrically by gaseous uranium fluoride (UF6) and then an outer shell of liquid lithium. A high power current would flow down the liquid lithium and the resulting Lorentz force would compress the column by roughly a factor of 10. The compressed column would reach criticality and a combination of fission and fusion reactions would occur. The fission reactions would further energize the fusion center, and the fusion reactions would generate neutrons that promote more complete burnup of the fission fuel. The lithium liner provides some help as a neutron reflector but also acts as a propulsive medium, being converted to plasma which is then expanded against a magnetic nozzle for thrust. The expansion of the (primarily) lithium plasma against the nozzle's magnetic field inducts a current that is used to charge the system for the next pulse. Our concept also included secondary injection of a Field Reversed Configuration (FRC) plasmoid that would provide a secondary compression direction, axially against the column, and push the column away from the injection manifold, increasing the manifold's survivability. Our phase 1 proposal included modeling the above process first under steady state assumptions and second under a time variant integration. We proposed including these results into a Mars concept vehicle and finally proposing promising conditions to be evaluated experimentally in Phase II. In phase I we quickly realized that we needed to modify our approach. Our steady state work was completed as proposed, and the results indicated that one, a two stage compression system was not needed and two, that we wanted to move away from UF6. The steady state model shows much more margin than expected, to the point that we may well reach break even with the Charger - 1 facility, a 572 kJ Marx bank currently under refurbishment at UAH. Additionally we found that using gaseous D-T and UF6, provided a relatively simple prospect of using a pulsed injector, made reaching criticality more difficult. The introduction of large amounts of fluorine meant a radiative sink, sapping power from the fusion plasma and was harder to handle. Therefore we moved to a solid uranium target that held D-T under pressure. In so doing we could move our target closer to criticality and remove any material that did not sustain the reaction. However in moving to a solid target we complicated our time-variant model, now requiring us to develop phase change algorithms and stress-strain calculations for the solid matrix. We have continued efforts along this line but as expected we did not complete this model. After discussions with NIAC management we moved some of our resources to preparing existing equipment to support an experimental program testing various target configurations under a variety of z-pinches at different power levels. Contained in this report are our results preparing 200 J, 1kJ and 4-8 kJ pulsed power systems as well as a vacuum chamber and diagnostic equipment to evaluate generated plasmas. We have also completed a point design of PuFF using the results of our steady state model. This design was then used to evaluate a couple missions of interest. At the behest of NIAC management we considered a more advanced version of the Mars mission, resulting in a vehicle that could reach Mars, one way, in 37 days with 25 mT of payload. This payload is consistent with a crew capsule or a Mars lander. We envision PuFF being used to carry high speed payloads to an existing Martian base. We also considered a robotic probe to the outer solar system and interstellar space. This probe, using the same point design for the engine, carries 10 mT to 1000 AU in 36 years, enabling exploration of the local space around our solar system. These missions were the most obvious ones for the point design, and it should be stressed that there is significant potential to increase capability and performance. The PuFF team did not consider more optimization or additional missions, expecting that successful Phase II funding and execution will provide a more accurate relationship between target configuration, engine design and mission capabilities. Finally we have put together our plan for future research, carried forward in a Phase II NIAC and beyond. As mentioned before concentrating on identifying the relationship between the target composition and geometry and the strength of the z-pinch is our highest priority. The composition and geometry will define the criticality of the target and potential energy release. The strength of the pinch defines the needed infrastructure to create the pinch, i.e. the engine mass. Both speak directly to the performance (specific impulse and specific power, respectively) of the concept. Our research plan, developed under Phase I, gives us the most economical path to determine these relationships and how to overcome limiting factors such as onset of plasma instabilities. In conclusion our steady-state results to date have shown PuFF to be a powerful new propulsion system capable of meeting a range of different mission requirements. There is substantial research to be done to address the limiting factors inherent in the PuFF concept, which is reaching criticality and avoiding plasma instabilities. Our time variant model continues under development and we have put into place a number of physical apparatus to support a future test program of pinching targets at various power levels. The test program is laid out both here and our Phase II proposal and we continue development as resources permit to bring PuFF to fruition and enable the next phase of space exploration for the 21st century.

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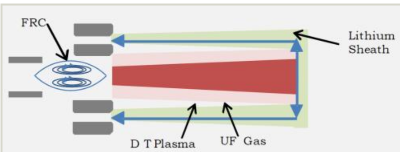
Images



Pulsed Fission-Fusion (PuFF) Propulsion System Concept Diagram
Pulsed Fission-Fusion (PuFF) Propulsion System Project
(https://techport.nasa.gov/image/102160)